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(54) **RADAR MODULE**

(57) The disclosure relates to a radar module, particularly to a phased array radar module for transmitting millimetre wave signals. Example embodiments include a phased array radar module for transmitting millimetre wave radar signals, the radar module comprising: an integrated circuit configured to generate a radar signal; and an antenna array (100) comprising a plurality of antenna elements (101-103) configured to transmit radar signals having a signal wavelength, each antenna element (101-103) comprising an antenna (101a, 102a, 103a) and a phase rotator (101b, 102b, 103b), each phase rotator being configured to shift the phase of the radar signal before transmission by the respective antenna, wherein the distance between each antenna of the antenna array (100) is less than half of the signal wavelength.

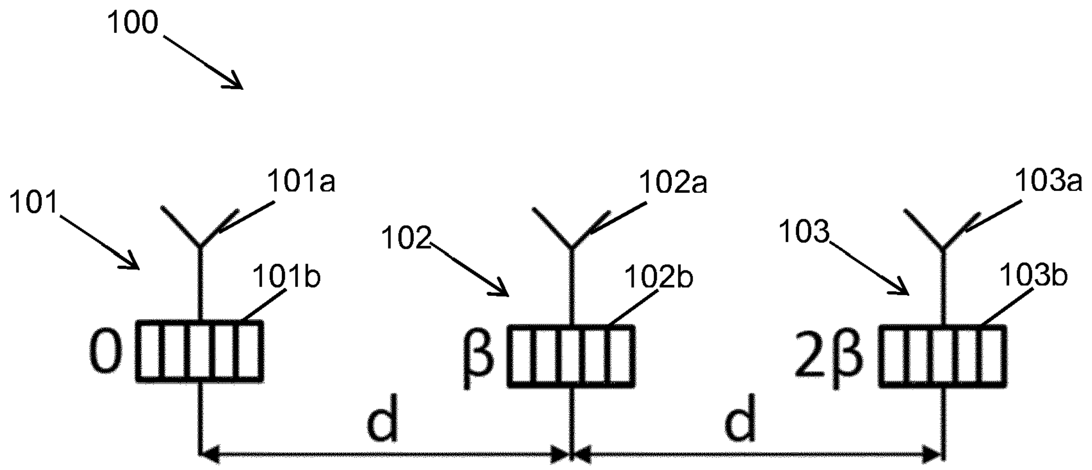

Fig. 1

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Description

Field

[0001] The disclosure relates to a radar module, particularly to a phased array radar module for transmitting millimetre wave signals.

Background

[0002] Phased arrays provide a beam of radio waves that can be electronically steered, adjusting the direction of the beam without physically moving the antennas. Phased arrays comprise a plurality of antenna elements, each element comprising a phase rotator for controlling the phase of the signal transmitted by that element.

[0003] The spacing between antennas in a phased array affects the field of view and the angular resolution of the array. Typically, an antenna spacing of $\lambda/2$ is used, where λ is the wavelength of the radar signal transmitted by the phased array.

Summary

[0004] In accordance with a first aspect of the disclosure, there is provided a phased array radar module for transmitting millimetre wave radar signals, the radar module comprising:

an integrated circuit configured to generate a radar signal; and
an antenna array comprising a plurality of antenna elements configured to transmit radar signals having a signal wavelength, each antenna element comprising an antenna and a phase rotator, each phase rotator being configured to shift the phase of the radar signal before transmission by the respective antenna,
wherein the distance between each antenna of the antenna array is less than half of the signal wavelength.

[0005] Millimetre wave radar signals may be those having a frequency between 30 and 300 GHz.

[0006] In conventional millimetre wave phased arrays, a spacing of $\lambda/2$ is used. Anything larger than this spacing leads to grating lobes. However, reducing the spacing between the antennas is a trade-off between the field of view (FoV) and the angular resolution of the antenna. Furthermore, for millimetre wave radar modules built using PCB production, it is difficult to make the antenna distance less than $\lambda/2$.

[0007] A number of methods are used in conventional radar modules to increase the scanning range (and hence FoV) of a phased array. For example, the number of antenna elements in the array may be increased, or the resolution of the phase rotators may be improved. These approaches provide small improvements in FoV, but have a high cost.

[0008] For millimetre wave radar applications, a wider FoV is of prime importance. Thus, a small reduction in angular resolution caused by a reduced spacing between the antennas may be tolerated, without reducing the radar performance of the phased array. It has been found that reducing the distance between the antennas may surprisingly lead to a greater increase in FoV of the array than the other approaches discussed above, at lower cost, and with only a small impact on angular resolution. For example, FoV may be increased by up to 20%, with only a small 1-2% reduction in angular resolution.

[0009] The distance between the antennas may be defined as the distance from the mid-point of one antenna to the mid-point of an adjacent antenna.

[0010] In some embodiments, the distance between each antenna may be larger than a quarter of the signal wavelength. Antenna to antenna distances between half a wavelength and a quarter of a wavelength yield the desired increase in FoV, but do not significantly increase production costs compared to conventional arrays.

[0011] In some embodiments, the distance between each antenna is larger than 0.4x the signal wavelength, or may be between 0.48x and 0.47x the signal wavelength. Surprisingly, it has been found that even such relatively small reductions in the distance between the antennas leads to a large improvement in FoV of the array.

[0012] In some embodiments, the antenna array may be incorporated with the integrated circuit in an antenna-in-package arrangement. For example, the antenna array may be incorporated with the integrated circuit in a fan-out package.

[0013] The difficulties of reducing the antenna-to-antenna distance in conventional PCB production techniques may be overcome by using an antenna-in-package arrangement. Antenna-in-package designs allow for production of compact radar modules, permitting reduction of the distance between the antennas.

[0014] In some embodiments, the antenna array may be incorporated with the integrated circuit in an embedded wafer level ball grid array(eWLB) package, a fan-out chip scale package (FO CSP), or a redistributed chip package (RCP).

[0015] In some embodiments, the radar module may further comprise one or more vias extending from a top surface of the module to a bottom surface of the module, wherein each via is located between a respective pair of adjacent antennas of the antenna array, the vias being configured to substantially isolate each antenna of the antenna array from adjacent antennas of the antenna array.

[0016] Isolating the antennas from each other with vias may reduce cross-talk, allowing the antenna-to-antenna distance to be reduced without substantially increasing cross-talk between adjacent antennas.

[0017] In some embodiments, each antenna of the antenna array may comprise a patch antenna.

[0018] In some embodiments, the antenna may be configured to transmit radar signals having a wavelength in the range 10mm to 1 mm.

[0019] These and other aspects of the invention will be apparent from, and elucidated with reference to, the embodiments described hereinafter.

Brief description of Drawings

[0020] Embodiments will be described, by way of example only, with reference to the drawings, in which

figure 1 illustrates an example phased radar array;
figure 2 illustrates a comparison of the antenna array function as a function of angle for a number of examples of phased radar arrays; and
figures 3a and 3b illustrate an example radar module.

[0021] It should be noted that the Figures are diagrammatic and not drawn to scale. Relative dimensions and proportions of parts of these Figures have been shown exaggerated or reduced in size, for the sake of clarity and convenience in the drawings. The same reference signs are generally used to refer to corresponding or similar feature in modified and different embodiments.

Detailed description of embodiments

[0022] Figure 1 shows a representation of an example phased array 100. Phased array 100 is a mm-wave array, i.e. configured to transmit radar signals with a wavelength λ between 1mm and 10mm. Phased array 100 comprises a plurality of antenna elements 101-103. Each antenna element comprises an antenna 101a, 102a, 103a configured to transmit signals of wavelength λ, and a phase rotator 101 b, 102b, 103c. Each antenna 101 a-1 03a is separated from adjacent antennas by a distance d, which in this case is measured between the midpoint of each antenna. As discussed above, conventionally $d = 0.5\lambda$. The antenna elements 101-103 receive a radar signal for transmitting from an integrated circuit (not shown). The phase rotators 101b-103b are x-bit (e.g. 3-bit, 4-bit, 5-bit, 6-bit, or 7-bit) phase rotators. The phase rotators 101b-103b control the phase of the signal transmitted by their respective antennas 101a-103a. The phase difference between signals transmitted by adjacent antenna element 101-103 is β By controlling the phase, the direction of the radar beam resulting from the combination of the signals transmitted by each antenna element 101-103 may be controlled. The maximum scanning range of this resultant radar beam, related to the field of view (FoV) of the array 100, is determined by the maximum tiling of the resultant radar beam and the width of the resultant beam. Although three elements 101-103 are shown in the illustrated example, any number of elements may be used, for example two, four, five, or more elements.

[0023] For mm-wave radar applications, it is desirable to increase the FoV of the array 100. Conventional techniques for improving FoV include increasing the number of antenna elements in the array, and increasing the resolution of the phase rotators.

[0024] Figure 2 illustrates the improvement in FoV that may be achieved with these techniques. Figure 2 shows the normalised antenna function AF as a function of azimuthal angle (with respect to the antenna array) for a number of example phased arrays. Line 201 shows the AF for a conventional 3-element array with a spacing of 0.5λ, each element comprising a 5-bit phase rotator. Line 202 shows the AF for a 3-element array with a spacing of 0.5λ and a 7-bit phase rotator. Line 203 shows the AF for a 4-element array with a spacing of 0.5λ and a 5-bit phase rotator.

[0025] The phased arrays represented by line 202 shows an improved FoV compared to the conventional array represented by line 201. However, the improvement is relatively small, and the techniques to improve the FoV are costly.

[0026] Line 204 represents a 3-element array with 5-bit rotators, but with a reduced antenna-to-antenna distance d of 0.475λ. Implementing such a small reduction in d is much less costly than the other techniques described above, but the FoV improvement is even greater than for those techniques, showing an increase in normalised AF of around 5dB at an angle of 160 degrees compared with the 3 element array having a 0.5λ spacing and 7 bit rotators (line 202), and around 7dB over the 3 element array having a 0.5λ spacing and 5 bit rotators (line 201).

[0027] Table 1 shows the beam parameters of the four arrays represented in figure 2. As can be seen from these data, the conventional FoV improvement techniques yield small increases in the normalised FoV (i.e. relative to the array of line 201). However, a much larger increase, up to 120% normalised FoV for *d*=0.475λ, is achieved by reducing the distance between the antennas.

Table 1: Beam parameters of the four arrays represented in figure 2.

No. Elements	Phase rotator	Phase difference, β	*d*	FoV	Normalised FoV
3	5-bit	45°	0.5λ	± 36.5°	100%
3	7-bit	50.6°	0.5λ	± 38.5°	105%
4	5-bit	33.75°	0.5λ	± 39.5°	108%
3	5-bit	45°	0.475A	± 44°	120%

[0028] Thus, by decreasing the antenna-to-antenna distance compared to the conventional *d*=0.5λ, a large increase in FoV can be achieved.

[0029] Conventionally, for 77 GHz automotive radar applications, PCB technology is used, with RO3003 being the most commonly used RF substrate. RO3003 has a relative dielectric constant of 3.0. All other RF substrates conventionally used for automotive radar applications have a similar dielectric constant. Due to this dielectric constant, it may be difficult to realise a dense antenna array with antenna-to-antenna spacing less than 0.5λ using conventional PCB technology.

[0030] Antenna-in-packaging provides an alternative option for building RF front-end radar modules. With antenna-in-packaging, it is possible to construct an RF front-end system with antenna-to-antenna spacing of less than 0.5λ. An example of a radar module using an antenna-in-packaging arrangement is shown in figures 3a and 3b.

[0031] Figure 3a shows a cross-section through a radar module 300. Radar module 300 uses an embedded wafer level ball grid array (eWLB) arrangement, a specific example of an antenna-in-package arrangement. Radar module 300 comprises a package block 301 resting on a ground-covered PCB 302. The package block 301 is suspended above the PCB 302 by solder balls 303.

[0032] The package block 301 comprises an integrated circuit (IC) 304. IC 304 generates radar signals that are to be transmitted. The radar signals are sent through feed lines 305 to patch antennas 306 (each associated with a phase rotator, not shown) for transmission. The plurality of patch antennas 306 together form a phased antenna array. The feed lines 305 communicate the radar signal to their respective antennas 306 via an encapsulation layer 307. Where feed lines 305 overlap, as in figure 3, apertures 308 may be used to couple a feed line 305 to a respective antenna 306. This design may allow the size of the patch antennas 306 to be minimised, enabling a reduction in the antenna-to-antenna distance.

[0033] Each antenna 306 is separated from adjacent antennas 306 by electrically conductive vias 309, each via extending from a top surface to a bottom surface of the package block 301. The vias 309 limit cross-talk between adjacent antennas 306, providing channel-to-channel isolation.

[0034] Figure 3b shows a top-side view of the radar module 300, showing a first antenna 306a and a second antenna 306b. A plurality of vias 309 surround each antenna, substantially isolating antenna 306a from antenna 306b (for clarity, not all vias 309 are labelled in the figure). Figure 3b also shows respective feed lines 305 to each antenna 306a, 306b, represented as dotted lines as they are located below the top surface of the package block 301.

[0035] Figure 4 shows a representation of the S_{11} scattering parameter for one of the antennas 306 in example radar module 300, illustrating the strong coupling between the feed lines 305 and the patch 206.

[0036] The compact design of radar module 300 allows the antennas to be separated by a distance d less than 0.5λ, for example they may be separated by a distance *d*=0.475λ. In other examples, *d* may take any value in the range $0.25\lambda < d < 0.5\lambda$. The wavelength λ of the radar signals transmitted by the radar module 300 may be in the range 1 mm to 10mm.

[0037] Thus radar module 300 provides a phased radar array with an improved field of view due to the reduced spacing between the antennas of the array.

[0038] From reading the present disclosure, other variations and modifications will be apparent to the skilled person. Such variations and modifications may involve equivalent and other features which are already known in the art of radar modules, and which may be used instead of, or in addition to, features already described herein.

[0039] Although the appended claims are directed to particular combinations of features, it should be understood that the scope of the disclosure of the present invention also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention.

[0040] Features which are described in the context of separate embodiments may also be provided in combination in a single embodiment. Conversely, various features which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination. The applicant hereby gives notice that new claims may be formulated to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

[0041] For the sake of completeness it is also stated that the term "comprising" does not exclude other elements or steps, the term "a" or "an" does not exclude a plurality, and reference signs in the claims shall not be construed as limiting the scope of the claims.

Claims

1. A phased array radar module for transmitting millimetre wave radar signals, the radar module comprising:

   an integrated circuit configured to generate a radar signal; and
   an antenna array comprising a plurality of antenna elements configured to transmit radar signals having a signal wavelength, each antenna element comprising an antenna and a phase rotator, each phase rotator being configured to shift the phase of the radar signal before transmission by the respective antenna,
   wherein the distance between each antenna of the antenna array is less than half of the signal wavelength.

2. The radar module of claim 1, wherein the distance between each antenna is larger than a quarter of the signal wavelength.

3. The radar module of claim 1, wherein the distance between each antenna is larger than 0.4x the signal wavelength.

4. The radar module of claim 1, wherein the distance between each antenna is between 0.48x and 0.47x the signal wavelength.

5. The radar module of any preceding claim, wherein the antenna array is incorporated with the integrated circuit in an antenna-in-package arrangement

6. The radar module of claim 5, wherein the antenna array is incorporated with the integrated circuit in a fan-out package.

7. The radar module of claim 6, wherein the antenna array is incorporated with the integrated circuit in an embedded wafer level ball grid array, eWLB, package, or in a fan-out chip scale package, or in a redistributed chip package.

8. The radar module of any preceding claim, further comprising one or more vias extending from a top surface of the module to a bottom surface of the module, wherein each via is located between a respective pair of adjacent antennas of the antenna array, the vias being configured to substantially isolate each antenna of the antenna array from adjacent antennas of the antenna array.

9. The radar module of any preceding claim, wherein each antenna of the antenna array comprises a patch antenna.

10. The radar module of any preceding claim, wherein the antenna is configured to transmit radar signals having a signal wavelength in the range 10mm to 1mm.

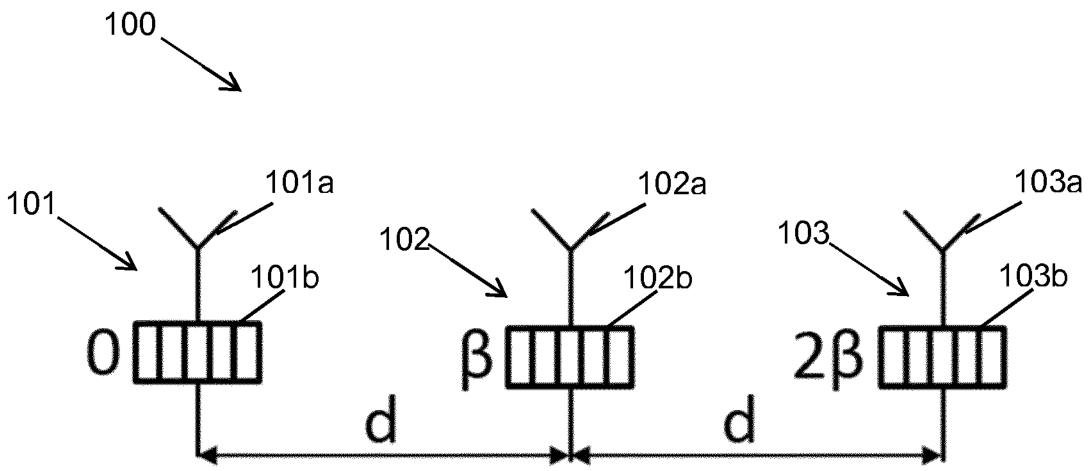
100
101
101a
101b
102
102a
102b
103
103a
103b
0
β
2β
d
d

Fig. 1

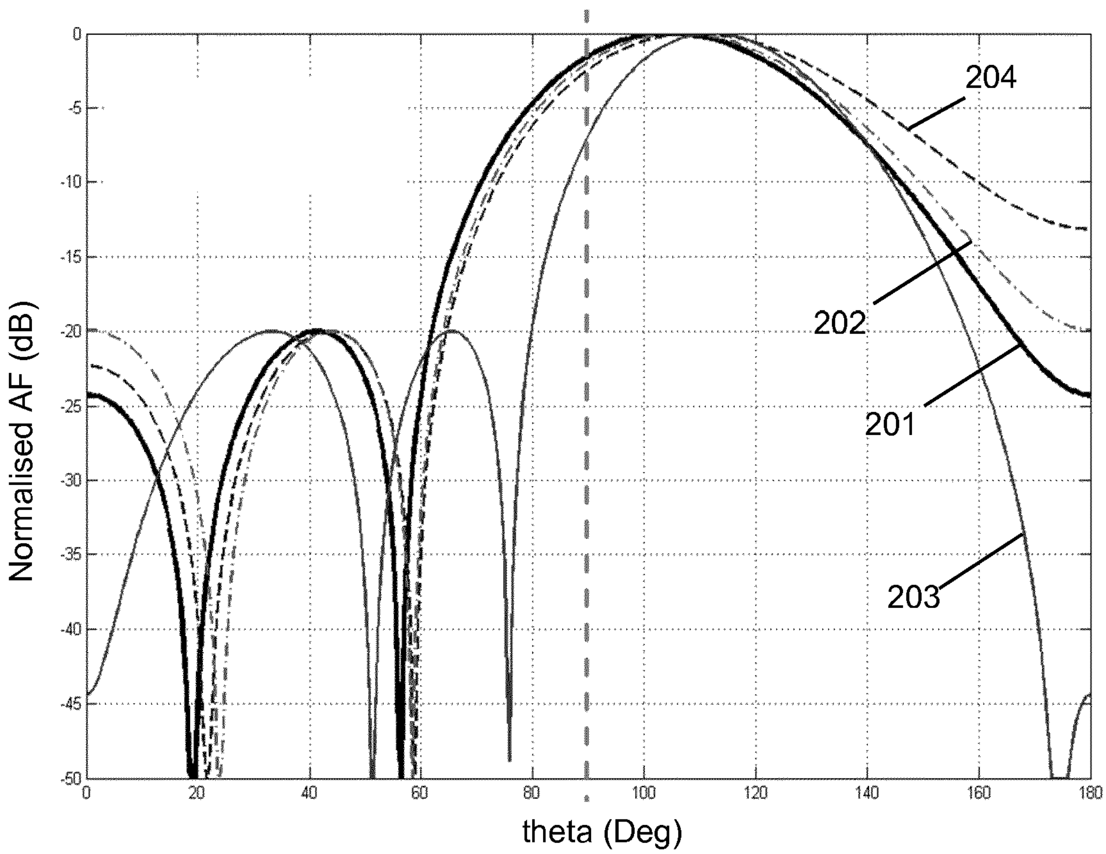
Normalised AF (dB)
theta (Deg)
201
202
203
204

Fig. 2

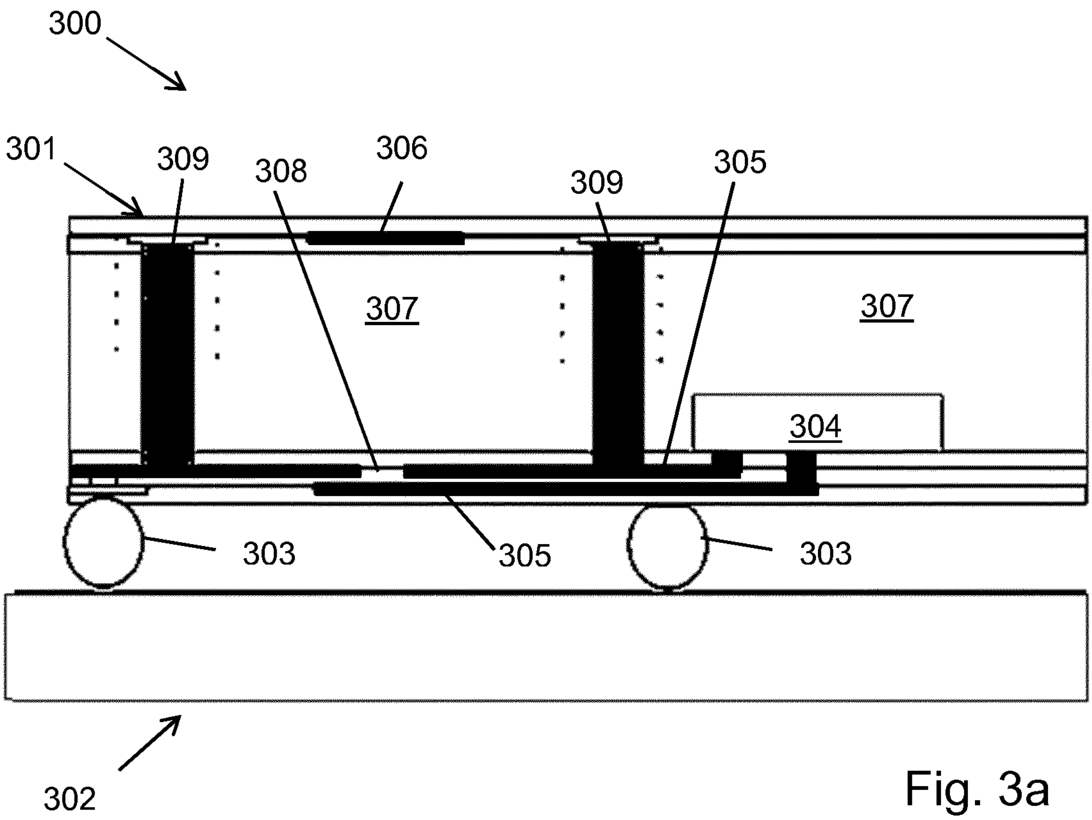

Fig. 3a

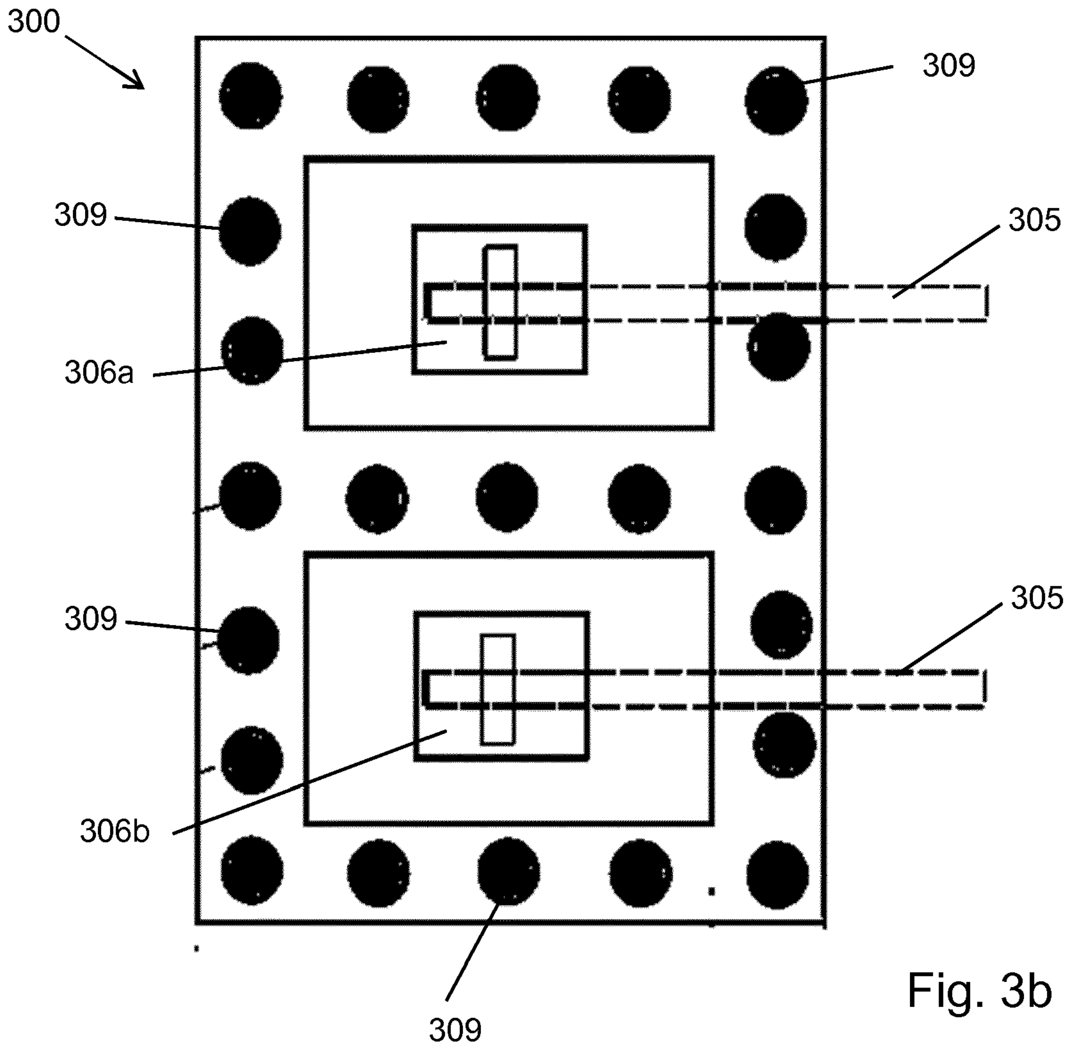

Fig. 3b

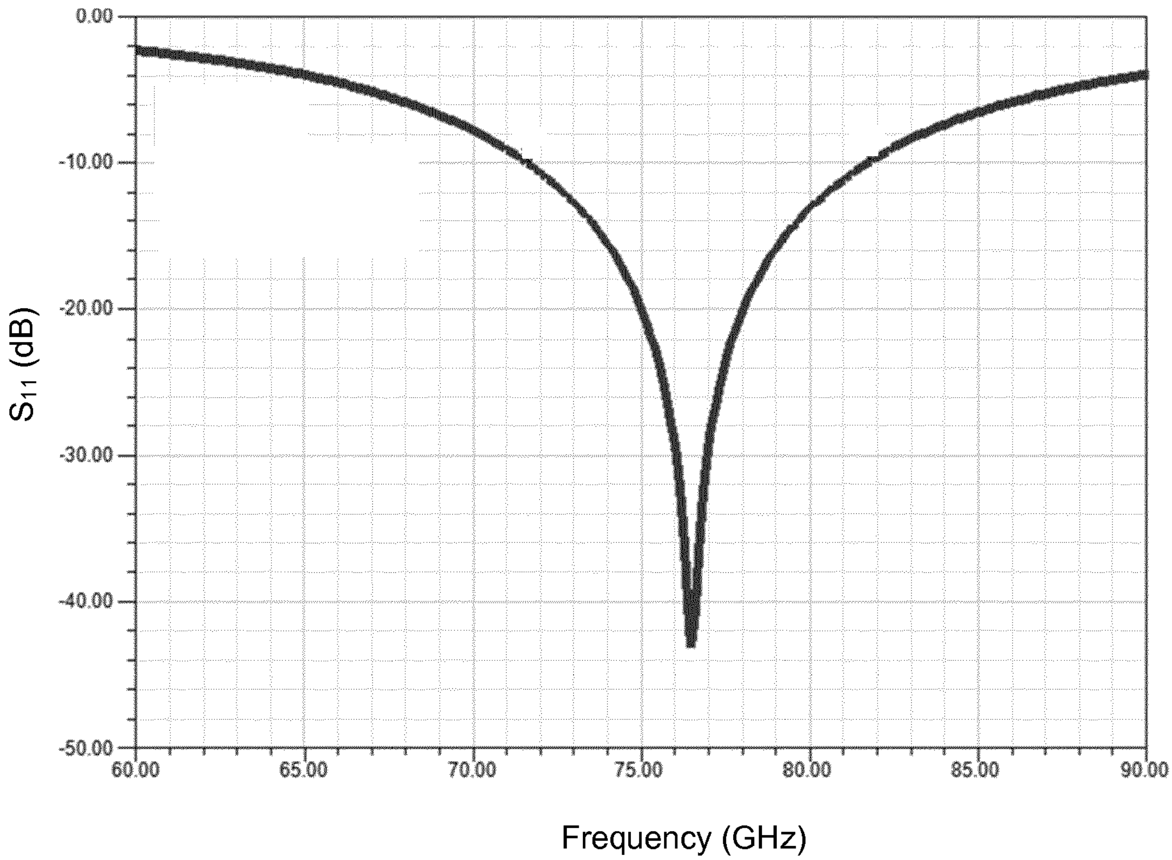
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
S11 (dB)
60.00
65.00
70.00
75.00
80.00
85.00
90.00
Frequency (GHz)

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 6293

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The present search report has been drawn up for all claims

6

Place of search	Date of completion of the search	Examiner
The Hague	19 February 2018	Taddei, Ruggero

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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